Accuracy of Intraoral Scanning of Edentulous Jaws with and without Resin Markers

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Objective: *To evaluate the accuracy of digital models obtained from intraoral scanning of edentulous maxilla and mandible models with and without resin markers.*
Methods: *A pair of standard edentulous models were scanned using a laboratory scanner and saved as reference models. The edentulous models were fixed onto a phantom head and scanned with an intraoral scanner (IOS) five times each. Six resin markers were attached on the maxilla model and two on the mandible model, and another five intraoral scans were taken of each model. The scanning time and number of images were recorded. The digital models obtained using the IOS were superimposed on the reference models using image processing software. The trueness and precision of the models made using the IOS were evaluated, and the scanning time and number of images were also compared.*
Results: *The average trueness and precision of the IOS in the maxilla model with resin markers were 135.50 ± 36.28 µm and 254.55 ± 40.62 µm, respectively, while those in the mandible were 161.40 ± 55.45 µm and 368.75 ± 91.03 µm, respectively. Placing resin markers on the edentulous maxilla and mandible did not improve the trueness of the IOS, but placing resin markers on the edentulous maxilla improved the precision and scanning efficiency. However, placing resin markers on the buccal shelf of the edentulous mandible decreased the precision and increased the scanning time.*
Conclusion: *Resin markers placed on the hard palate of edentulous maxillae could improve the precision of the IOS and improve scanning efficiency. However, they did not affect the trueness of the IOS for edentulous maxillae or mandibles.*
Key words: *accuracy, edentulous, efficiency, intraoral scan, resin markers*
Chin J Dent Res 2020;23(4):265–271; doi: 10.3290/j.cjdr.b867887

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This study was funded by the Program for New Clinical Techniques and Therapies of Peking University School and Hospital of Stomatology (PKUSSNCT-18A04 & PKUSSNCT-20G03).

In the past several decades, a hybrid and fully digital workflow has been adopted in prosthodontic practice, and digital impression (DI) techniques have developed rapidly. Studies have shown that use of an intraoral scanner (IOS) has comparable accuracy to conventional impression (CI) techniques in fixed prostheses, suggesting that it can be adopted clinically in the fabrication of dental crowns[1], bridges[2] and implant-supported prostheses[3,4].

Intraoral scanning has many advantages compared to CI techniques; for example, the physical distortion of impression material and stone casts can be avoided, and for patients with a severe gag reflex or allergies, it has proven to be a more comfortable choice compared to CI[5]. An IOS was recently used in the fabrication of removable partial dentures[6] and proved to be a viable

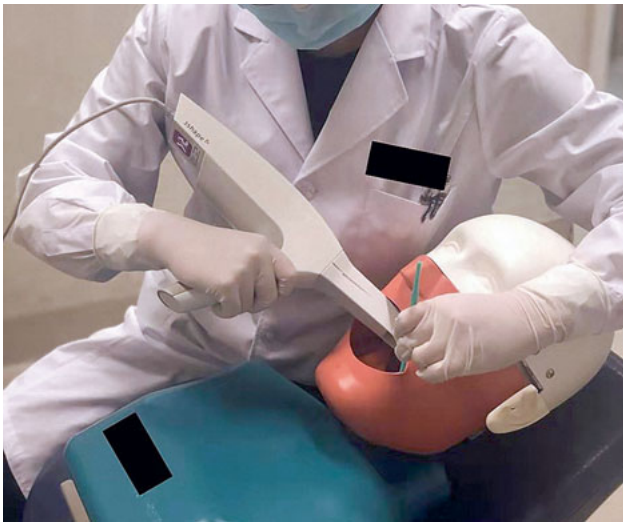

Fig 1 Intraoral scanning of the standard edentulous models mounted in a phantom head.

solution for impression taking. With the success of the abovementioned adoption of this device in the clinical procedure, an increasing number of researchers are trying to integrate use of an IOS in the reconstruction of edentulous jaws.

However, many unfavourable factors related to edentulous jaws make it difficult to take digital impressions using an IOS. For instance, the resorption of residual ridge can result in flat maxillary and mandibular contouring that is difficult to capture using the scanner[7], the size of the scanner head may prevent images from being captured on the buccal side of tuberosity[8], the mobile mucosa in the vestibule and floor of the mouth[9] and reflection of saliva can obstruct the acquisition of images[10], and instability of the dentist's hands during the scanning process may result in image distortion[11]. One of the most common phenomena is a lack of discernible markers for image stitching[10]. All these factors will negatively affect the quality of intraoral scans or even lead to impression failure. Even though several studies[9,12,13] report cases of complete denture fabrication using digital models made from scans of edentulous jaws taken with an IOS, quantitative analysis is still not available.

Patzelt et al reported trueness of 41.1-591.8 µm and precision of 21.6-698.0 µm in the results of an in vitro study on intraoral scanning of edentulous jaws[11]. The authors mentioned that a lack of anatomical markers in the palate area might influence the accuracy[11]. To solve this problem, it was suggested that resin markers could be set on the palatal mucosa[10,14] or opaque lines drawn on the surface of the palate[15] to facilitate the scanning procedure, and the clinical outcomes were proven to be successful. However, no quantitative analysis has been conducted to verify the effect of these methods.

Therefore, the aim of this study was to evaluate the accuracy and feasibility of intraoral scanning of edentulous maxillae and mandibles and to determine whether resin markers set on edentulous mucosa can improve the accuracy of scans of edentulous jaws taken using an IOS. The null hypotheses were that the trueness and precision of the optical edentulous models with resin markers were equal to those of the optical models without resin markers, and that there was no difference in the IOS scanning time and number of pictures between edentulous casts with resin markers and those without.

Materials and methods

Acquisition of digital data

Simulation of intraoral scan on a mannequin

The edentulous maxilla and mandible casts were fixed in a mannequin's mouth (Fig 1). The mannequin was adjusted to simulate a patient in a 45-degree reclining sitting position.

Reference digital impressions of edentulous jaws

A pair of standard edentulous casts (Dental Model, Nissin Dental Products, Kyoto, Japan) were prepared as original reference models (Figs 2a and 2b) and scanned using a laboratory desktop scanner (inEOS X5, accuracy 5-15 µm; Dentsply Sirona, Charlotte, NC, USA). The digital models were exported in STL form (Dental System, 3Shape, Copenhagen, Denmark) and used as reference digital models (R_{lab}).

Intraoral scans of edentulous casts without resin markers

A trained dentist conducted intraoral scanning of the edentulous maxilla and mandible with an IOS (TRIOS 3, 3Shape) five times each with a 10-minute interval between each scan. A zig-zag scanning pattern was applied: in the maxilla, the scanning started from one tuberosity and the IOS was moved from the buccal to the palatal side of the alveolar ridge and then back, ending at the tuberosity on the other side. Then the palatal area was scanned to finish the whole edentulous maxilla. A similar scanning protocol was applied in the mandible. The intraoral scan results were exported in STL form, and the scanning time and number of pictures taken in the scanning procedure were recorded.

Intraoral scans of edentulous casts with resin markers

Some researchers reported poor imaging quality in the flat area of edentulous maxillae and mandibles, for instance the palate and buccal shelf area[11]. Several clinical case reports showed models made using an IOS with resin markers on the palate area and reported improved quality of the digital models after using this strategy[10,14,15]. Based on these previous findings, hemispherical 3-mm diameter resin markers were designed and schematically attached to the mucosal surface of edentulous casts using flowable resin material (Filtek Z350 Flowable Restorative; 3M ESPE, Minneapolis, MN, USA). In the maxilla, six resin markers were attached on the palatal area. One was placed on the midline of the palate 25 mm posterior to the centre of the incisive papilla; two were placed on the left and right sides of the first resin marker 10 mm apart; a fourth was placed on the midline of the palate 35 mm posterior to the centre of the incisive papilla; and the final two were placed 15 mm horizontally to the fourth marker, one on each side (Fig 2c). In the mandible, two resin markers were placed in the centre of the buccal shelf area, one on each side (Fig 2d)

After the resin markers were firmly attached to the mucosa, the edentulous maxilla and mandible casts were fixed in the phantom mouth and scanned five times each following the same protocol as for the group without resin markers. The ten IOS files (five for the maxilla and five for the mandible) were exported in STL form, and the scanning time and number of pictures were recorded.

Data analysis

The STL data from each group was further processed and analysed using image processing software (Geomagic Control14, 3D Systems, Rock Hill, SC, USA).

The accuracy of the digital model was presented in terms of precision and trueness. Trueness describes how far the measurement deviates from the actual dimension of the measured object, and precision describes how close the repeated measurements are to each other.

To evaluate the trueness, each of the digital models created using the IOS was superimposed on the R_{lab} and the best fit algorithm was adopted. In the 3D analysis module, the root mean square (RMS) value between each IOS model and the R_{lab} was calculated using the following formula:

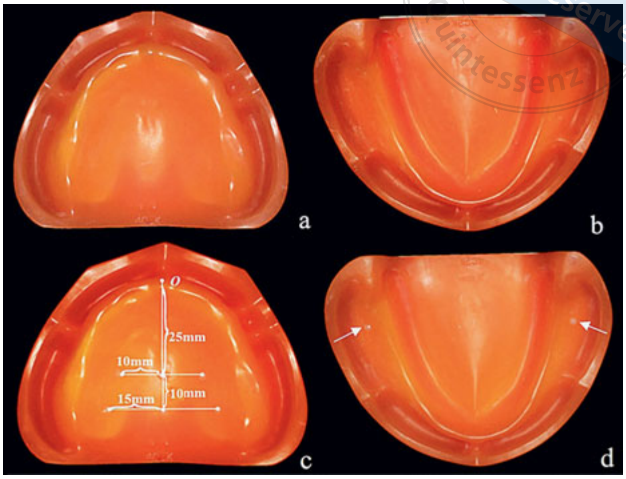

Fig 2 Standard edentulous models without and with resin markers. **(a)** The maxillary edentulous model without resin markers. **(b)** The mandibular edentulous model without resin markers. **(c)** The maxillary edentulous model with resin markers; O indicates the centre of the incisive papilla. The first resin marker was 25 mm posterior to O along the midline, the second and third markers were set at a 10-mm distance from the first resin marker on both sides of the midline the fourth marker was 35 mm posterior to O along the midline, and the fifth and sixth markers were set 15 mm from the fourth one on both sides. **(d)** The mandibular edentulous model with resin markers; the arrows point to the two resin markers placed in the centre of buccal shelf area.

$$XRMS= \sqrt{\frac{1}{n}\left(x_1^2 + x_2^2 + \cdots x_n^2\right)}$$

The RMS can be calculated using the 3D coordinates of the measured object, and its value represents the difference between the reference and the measured surface. The smaller the RMS is, the more accurate the measured surface is compared to the reference.

To evaluate precision, the IOS model with the smallest 3D RMS value compared to R_{lab} was set as the reference IOS model (R_{ios}) for precision assessment. The other IOS digital models were superimposed on R_{ios}, and the RMS value between each IOS model and R_{ios} was calculated. The smaller the RMS, the better the precision of the IOS model.

All the data were processed using statistical software (IBM SPSS Statistics v23.0; IBMCorp, Armonk, NY, USA). A two-way ANOVA and least significant difference (LSD) post hoc test were used for analysis of the RMS value. For the maxilla and mandible, a one-way ANOVA and Scheffe post hoc test were conducted to analyse the scanning time and number of pictures, respectively. The significance level was set at $\alpha = 0.05$ for all analyses.

Table 1 RMS between IOS digital models of edentulous jaws with or without resin markers and R_{lab} in 3D trueness analysis.

3D trueness	With resin markers (mean ± SD)	Without resin markers (mean ± SD)	P value
Maxilla	135.50 ± 36.28 µm	126.30 ± 24.00 µm	0.649
Mandible	161.40 ± 55.45 µm	156.60 ± 67.49 µm	0.905
P value	0.408	0.372	

Table 2 RMS between IOS digital models of edentulous jaws with or without resin markers and R_{ios} in 3D precision analysis.

3D precision	With resin markers (mean ± SD)	Without resin markers (mean ± SD)	P value
Maxilla	254.55 ± 40.62 µm	345.80 ± 60.13 µm	0.046
Mandible	368.75 ± 91.03 µm	107.28 ± 66.55 µm	0.004
P value	0.062	0.002	

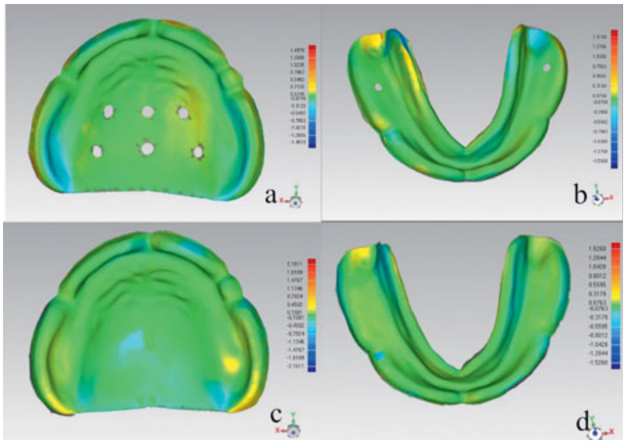

Fig 3 3D analysis of trueness. **(a)** Intraoral scan of maxillary model with resin markers superimposed on the maxillary R_{lab}. **(b)** Intraoral scan of mandibular model with resin markers superimposed on the mandibular R_{lab}. **(c)** Intraoral scan of maxillary model without resin markers superimposed on the maxillary R_{lab} without resin markers. **(d)** Intraoral scan of mandibular model without resin markers superimposed on the mandibular R_{lab}. The blue and yellow areas showed greater deviation compared to the green area. For the models with and without resin markers, greater deviation was observed in the posterior area.

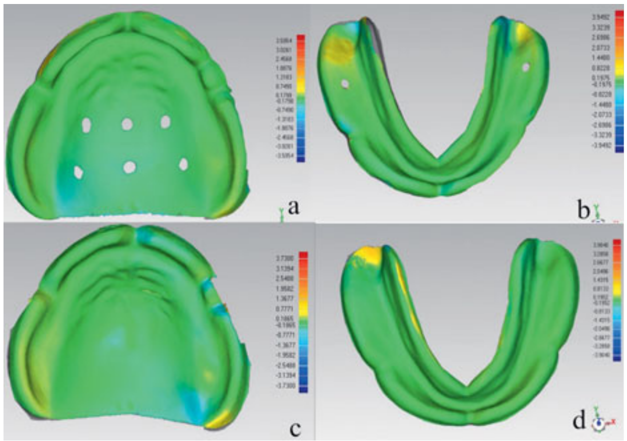

Fig 4 3D analysis of precision. **(a)** Intraoral scan of maxillary model with resin markers superimposed on the maxillary R_{ios}. **(b)** Intraoral scan of mandibular model with resin markers superimposed on the mandibular R_{ios}. **(c)** Intraoral scan of maxillary model without resin markers superimposed on the maxillary R_{ios} without resin markers. **(d)** Intraoral scan of mandibular model without resin markers superimposed on the mandibular R_{ios} without resin markers. The blue and yellow areas showed greater deviation compared to the green area. For the models with and without resin markers, greater deviation was observed in the posterior palate, vestibule and retromolar pad area.

Results

3D trueness analysis

The RMS for intraoral scans of the maxilla and mandible with or without resin markers compared with R_{lab} are shown in Table 1. For both the maxillary and mandibular edentulous models, no significant difference was found for trueness of the IOS between the model with resin markers and the model without. For IOS models with resin markers and those without, no significant difference was observed for trueness of the IOS between the maxilla and mandible.

Superimpositions of maxillary and mandibular intraoral scans on the corresponding R_{lab} models are shown in Fig 3, with the 3D analysis RMS result between the IOS and R_{lab} models displayed using a colour spectrum. For IOS models with resin markers and those without, a larger deviation from the R_{lab} model was observed in the posterior area of the model (yellow and blue area).

3D precision analysis

The average RMS between maxillary IOS models with resin markers (n = 4) and the maxillary R_{ios} model was 254.55 ± 40.62 µm (Table 2); this was significantly smaller than that for models without resin markers (345.80 ± 60.13µm) (P = 0.046). This indicated that using an IOS for maxillary models with resin markers

Table 3 Scanning time and number of images for IOS digital models of edentulous models with or without resin markers.

Area	Group	Scanning time, s (mean ± SD)	P value	Number of images (mean ± SD)	P value
Maxilla	With resin markers	338 ± 35.49	0.007	1324.20 ± 126.77	0.008
	Without resin markers	419.2 ± 28.28		1593.40 ± 88.29	
Mandible	With resin markers	320.2 ± 19.66	< 0.001	1245.40 ± 71.23	< 0.001
	Without resin markers	188.8 ± 22.92		858.80 ± 74.42	

was more precise than for those without resin markers.

The average RMS between the mandibular IOS models with resin markers (n = 4) and the mandibular R_{ios} was 368.75 ± 91.03 µm (Table 2); this was significantly larger than that for models without resin markers (107.28 ± 66.55 µm) ($P = 0.004$). This showed that using an IOS for mandibular models with resin markers was less precise than for those without resin markers.

For the group with resin markers, there was no significant difference in precision of the IOS between the maxilla and mandible ($P = 0.062$) (Table 2). For the group without resin markers, the mean RMS for the intraoral scan of mandibular models was significantly smaller than that for maxillary models ($P = 0.002$) (Table 2), which indicates that using an IOS for mandibular edentulous models was more precise than for maxillary models when there were no resin markers.

Superimpositions of maxillary and mandibular IOS models on the corresponding R_{ios} models are shown in Fig 4, with the 3D analysis result for the RMS between the IOS and R_{ios} models displayed using a colour spectrum. For all the IOS models, a larger deviation was observed in the posterior palate, vestibule and retromolar pad area (yellow and blue area).

Scanning time and number of pictures for IOS

Since the mucosal area of the maxilla is larger than that of the mandible, a longer scanning time and more pictures were required. We analysed the scanning efficiency between the groups with and without resin markers for the maxilla and mandible, respectively.

As shown in Table 3, in the maxilla, the mean intraoral scanning time for the model with resin markers was significantly shorter than for the model without resin markers ($P = 0.007$). Similarly, the mean number of pictures for the maxillary IOS model with resin markers was also less than that for the maxillary IOS model without resin markers ($P = 0.008$).

In contrast, the mean intraoral scanning time for the mandibular model with resin markers was longer than that for the model without resin markers ($P < 0.001$), and the mean number of pictures for the mandibular IOS model with resin markers was also greater than for the model without resin markers ($P < 0.001$).

Discussion

The accuracy of digital impression is one of the key determinants for the success of denture design and manufacture. In this in vitro study, a mannequin was used to simulate the actual clinical situation, with the phantom patient being set in a 45-degree reclining seated position, and the accuracy of intraoral scans of edentulous maxilla and mandible models was evaluated.

Trueness of intraoral scans of edentulous maxilla and mandible

In this study, the average RMS between the IOS models and R_{lab} models ranged from 126.30 to 135.5 µm in the maxilla and 156.60 to 161.40 µm in the mandible. There was no statistically significant difference in the trueness of the intraoral scans between models with resin markers and those without, nor between the edentulous maxilla and mandible. The accuracy of use of an IOS for edentulous jaws reported in this study was comparable to that reported by Patzelt et al[11]. They evaluated the accuracy of digitalised edentulous jaws using four different IOS[11]. They reported the average trueness of the different devices as between 44.1 ± 5.0 µm and 591.8 ± 377.9 µm, with no significant difference in the devices' trueness between the maxilla and mandible. The IOS with the highest trueness in Patzelt et al's study was based on active wavefront sampling and powder spray was needed for image capture[11], while the IOS used in this study was based on confocal microscopy and was powder-free. The difference in accuracy between scanners might be due to the difference in scanning protocol.

One study reported that the mucosal thickness in the palate area was around 2 to 3.3 mm[16] and the resilience of soft tissue covering the edentulous ridge and palate may compensate for the deviation of digital impressions taken using an IOS, with a deviation of less than 165 µm being acceptable in the clinical situation[17]; therefore, an IOS can be used for clinical cases to fabricate complete dentures and achieve acceptable clinical results[9,12,13,18].

The result of the 3D analysis of trueness (Fig 3) showed that a larger deviation could be observed in the posterior area of the tuberosity and vestibule, and in the retromolar pad in the mandible. The covering mucosa was thicker in some areas than others and some areas were covered with non-keratinised mucosa. The mobile mucosa were difficult to capture during scanning, especially when the movement of the scanner head was limited by the small interocclusal distance in the back part of the oral cavity.

Many factors can induce deviation during intraoral scanning. Operator experience can be a contributing factor, for example if the hands shake during scanning, and inaccurate scanning patterns could introduce more deviation into the final result. Anatomical factors should also be taken into account. It is difficult for the scanner head to fit in the buccal vestibule, and the posterior palate and retromolar pad were at the end of the edentulous maxilla and mandible; these factors make it difficult for the IOS to detect and match the pictures. Layering defects and mismatching were frequently observed during our scanning process.

Precision of intraoral scans of edentulous maxilla and mandible

Precision represents the repeatability of an intraoral scan. For the maxilla, the scan for the model with resin markers demonstrated better precision. This might be associated with the shape of the palate, which was flat and lacking in discernible character. When resin markers were attached on the posterior palate, more recognisable characteristics were provided to the IOS for image stitching, and the distortion and mismatching of pictures could be detected immediately during the scanning process, and the necessary corrections made in time. In the mandible, however, the scan for the model without resin markers demonstrated better precision. Even though the buccal shelf in the edentulous mandible was flat, it was still easy for the IOS to capture the whole surface directly due to its narrow width. After resin markers were attached, a higher number of pictures and longer scanning time were required to scan the mucosa around the resin markers, meaning that accumulative errors could occur and lower the general precision. In the group without resin markers, the mandible demonstrated significantly better precision than the maxilla. Since the resin markers increased the scanning precision for the maxilla but negatively influenced the precision for the mandible, in the group with resin markers, no statistically significant difference was found between the maxilla and mandible.

Scanning time and number of pictures

Due to the larger scanning area in the maxilla compared to the mandible, a longer scanning time and higher number of images were needed for the maxillary intraoral scan than for the mandibular scan. Thus, we analysed the influence of resin markers on the scanning efficiency for the maxilla and mandible respectively.

After resin markers were attached, the scanning time for the maxilla decreased. Placement of resin markers in the palatal area of the edentulous maxilla can improve the efficiency of image matching. In contrast, the scanning time and number of images for the mandibular intraoral scan increased after resin markers were placed in the buccal shelf area. This might be linked to the shape of this area. The limited space in the buccal shelf area impeded the scanning procedure, and it took more time to fully capture images of the mucosa around the resin markers.

Effectiveness of resin markers

The results from this study show that placing resin markers on the palatal area of the edentulous maxilla could improve the precision of the IOS and reduce the scanning time and number of images required to establish a 3D digital model using an IOS, while placing resin markers on the buccal shelf area of the edentulous mandible will negatively influence the precision of an IOS and increase the scanning time and number of images required. Other researchers recorded similar findings to ours[10,14]. Some have pointed out that the lack of anatomical landmarks in the palate area of the edentulous maxilla could lower the accuracy of intraoral scans[10,15]. Fang et al placed resin points on the hard palate to enhance image matching during intraoral scanning and found that the digital impression of the edentulous maxilla could be taken more efficiently, and image mismatching was less frequently observed[10]. Chebib et al placed landmarks on the mucosa in edentulous jaws using small spots of light-polymerised gingival barrier material and reported 0.70 ± 0.18 mm accuracy of the IOS; this result was deemed acceptable in clinical work[14]. The accuracy detected in the present study was greater than that in Chebib et al's study, and the present findings provided evidence that the IOS models were acceptable for clinical use. We also found that intraoral scanning required more operator experience for edentulous maxilla than for natural dentition, especially in the palate area where image distortion and mismatching often occurred in the posterior area of the arch. Although no significant change in trueness was found after placement of the resin markers, the precision in the maxilla was improved and scanning efficiency was enhanced significantly.

This study displayed several limitations. The sample size is limited and bias could be introduced. For intraoral scanning of models with resin markers, the markers were deleted in the image processing software for better superimposition, which could influence the RMS calculation. It must be noted that this is an in vitro study, the mouth opening in the phantom head was wider than that in an actual patient, and there was no flow of saliva or obstruction caused by the tongue, therefore the trueness and precision of intraoral scans of edentulous jaws in actual patients would be different. More studies are needed to further evaluate the accuracy in vivo.

Conclusion

Resin markers on the hard palate in the edentulous maxilla improved the precision of the IOS and decreased the scanning time and the number of pictures taken. However, placing resin markers on the buccal shelf of the edentulous mandible decreased the precision of the IOS and increased the scanning time. The trueness of intraoral scanning in edentulous jaws was not affected by the presence or absence of resin markers on edentulous mucosa.

Acknowledgements

The authors express their gratitude to Mr Bing WANG and Ms Wen Hui GAO (Dental Technicians, Laboratory Centre, Peking University School and Hospital of Stomatology) for their instruction in the usage of the laboratory scanner.

Conflicts of interest

The authors declare no conflicts of interest related to this study.

Author contribution

Drs Chang TAO, Yi Jiao ZHAO, Qiu Fei XIE and Shao Xia PAN conceived the ideas; Dr Chang TAO collected the data; Drs Chang TAO, Yu Chun SUN, Yi Jiao ZHAO, Mo Di HENG and Shao Xia PAN analysed the data; Drs Chang Tao and Shaoxia Pan wrote the manuscript.

(Received Feb 28, 2020, accepted Jun 5, 2020)

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